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Growth in Relation to Temperature

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GROWTH IN RELATION TO TEMPERATURE

BY

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I INTRODUCTION

A relation between temperature and growth has long been recognized. That a rising temperature is attended with an increased rate of growth, and vice versa, is a fact universally accepted. It too is a generally accepted conclusion that the growth curve in relation to temperature shows three cardinal points: the minimum, a temperature below which no growth is exhibited; the optimum, at which growth is greatest; and the maximum, at which growth again comes to a standstill.

Much discussion has recently appeared in the literature concerning the true position and the meaning of the optimum. The earlier investigators, Sachs (1), DeVries (2), Koeppen (3), in their studies on the effects of temperature on growth, subjected the plant to a given temperature for a longer or shorter period of time, and measured the increment of growth for that period. The temperature at which the greatest growth, within the period chosen, took place was considered the optimum.

A careful study of the published data on the optimum temperature for growth reveals a rather wide variance in its position in the curve. Sachs (1) placed it at 34°C. for seedlings of flowering plants, and at 33.7°C. for the plumule of Zea mais. Koeppen (3) gives as the optimum for the plumule of mais 30°C. and $33\frac{1}{2}$°C; De Candolle (4) places it, for the same seedling, at 28°C. The fact that the optimum temperature for the seedling of Zea mais, as well as for the seedlings of other plants, has been placed by different workers at rather widely different temperatures makes it desirable to reinvestigate the problem. The methods used by former investiga-

tors have been essentially the same; and the accuracy of their observations cannot be questioned. In seeking an explanation for the rather wide discrepancies we must consequently endeavor to find the factor, not heretofore considered, which is responsible for the difference in the position of the optimum.

Recent work on the effects of temperature on respiration, as reported by Claussen (5), on fermentation as reported by Chudiakow (7), and on photosynthesis, as reported by Miss Matthaei (6), leads one to conclude that possibly the time factor, so important in the consideration of the optimum temperature for these physiological processes, plays an equally important role in the consideration of the optimum temperature for growth. In the important contributions of Blackman (8) and Jost (9) we have, for the first time, clearly pointed out that the time-factor is of fundamental importance in a consideration of the cardinal points of physiological activities. For photosynthesis the initial rate of activity is not maintained at high temperatures for any considerable period, but after a short time it decreases with more or less rapidity. The same holds true for other physiological processes as respiration, fermentation, etc. Owing to this more or less rapid decrease in the initial rate of physiological action at high temperatures, the position of the optimum will shift with the temperature and the time elapsing between the application of a given temperature and the first reading. For example, recent work along these lines shows that the position of the optimum activity of a physiological process, like respiration or photosynthesis, is placed at a higher temperature by the observer who takes his reading after one hour than by another who takes his first reading after three hours. In all the work heretofore done on the relation between growth and temperature, the data was secured from a single

reading, and that usually taken after the plant had been subjected to a given temperature for a period of forty-eight hours. To be true some investigators have measured the increments of growth at much shorter intervals but they did not consider a sufficiently wide range of temperatures. Askenasy (10) in his experiments on the growth of roots of mais did not go beyond 28--29°C. Godlewski (11) worked only with medium temperatures. True (12) did not carry his experiments beyond a temperature of 30°C., the so-called optimum.

One of the classical papers on the relation of temperature to growth is that of Koeppen (3). Koeppen, working with the seedlings of a number of different plants, showed that the growth-curve in relation to temperature is quite irregular and that, in most instances, it shows a double optimum. For mais he finds the two optima to lie at 30°C. and 33½°C., with a decided drop in the curve at intervening temperatures. The double optimum of Koeppen is referred to in text-books of advanced Plant Physiology and his data are considered in greater or less detail in all recent work on growth.

Koeppen attempts no explanation for the double optimum. He suggests that possibly between the temperatures of 30°C. and 33½°C. some chemical processes are active which have a retarding effect on growth.

Owing then to the fact that the optimum temperature for growth has been given at rather widely different temperatures, and in one important paper at two temperatures, a reinvestigation of growth at a sufficiently wide range of temperatures, and with due consideration of the time factor, was deemed advisable. The investigation was undertaken at the suggestion of Professor C. F. Hottes and was carried on in the Botanical Laboratory at the University of Illinois. It is with pleasure that I acknowledge my indebtedness to Professor

Hottes for suggesting the problem, and for valuable and helpful criticisms, especially in the construction of the apparatus.

II APPARATUS

In taking up this complex problem it becomes essential to observe a number of fundamental factors that seriously affect the accuracy of the results. It must be recognized at the outset that the air in the plant chamber be pure, that is, that the vitiated air of the laboratory be excluded: that its moisture content be possible of accurate adjustment and maintenance: that the temperature be maintained uniform for relatively long periods of time and be changed readily and conveniently when desired: and, finally, the readings of the growth increments be made with accuracy and without disturbing the plant or altering the conditions for its growth.

The apparatus, illustrated in Plate I, was devised to secure these conditions. It consists in the main of the following parts;

1. The thermostats
2. The constant humidity arrangement
3. The plant chambers

1. The Thermostats

There are four thermostats. One is a large tank, 1 x 2½ x 3½ feet, filled with water in which the air is heated by passing through Winkler coils, and charged with moisture by passing through a saturation chamber. The other three thermostats, containing the plant chambers, are smaller, 8 x 13 x 13 inches, and are provided with glass front and back, covered during the experiment with an opaque leatheret curtain to exclude the light.

The thermostats are supplied with electric heating coils so arranged that the water is constantly driven through them by a set of four stirrers. A thermometer, suspended in the water, registers

the temperature.

The temperature is controlled and kept constant by means of a set of Smith automatic thermo regulators. The regulators, properly secured to a base, are placed in Eastman 4 x 5 plate developing tanks, provided with lead outlets for the electric connections. These tanks proved very serviceable, since the lids can be removed readily for adjusting the regulators, and are absolutely water tight.

2. Constant Humidity Arrangement

Air drawn from out-of-doors is deprived of its moisture by passing it through calcium chloride and concentrated sulphuric acid. It is then recharged with a definite amount of moisture by passing it through a large chamber containing a salt solution of definite and known concentration and constant temperature. The tension of the water vapor above such a salt solution is less than that formed above distilled water, and diminishes as the concentration of the salt solution increases. The hygrometric condition of the air after passing through such a solution may be calculated by means of the formula $1 - na$*; in this formula saturation is taken as unity; n equals the number of grams of salt dissolved in 100 grams of water, and a is a constant; this for sodium chloride is 0.00601.

The air, charged with a definite amount of moisture, takes a course as follows: By means of two aspirators, so connected that they may be used singly or together, the air is exhausted from the plant chambers. These in turn are furnished with fresh air from the large saturation chamber which is connected with the plant

*Cf. LeSage--Ann.Sci.Nat.Bot. (8) 1: 309, 1895.

chambers by means of lead pipes. Since a slight cooling of the air in the passage alters the moisture content, smaller saturation chambers are provided next the plant chambers in the small thermostats, in which the air is recharged. By means of mercury manometers, connected with the plant chambers, and a series of stopcocks in the supply pipes, the rate of the flow of air and the pressure are regulated.

3. The Plant Chambers

The plant chambers were constructed of glass jars, 9½ x 4-3/4 x 4-3/4 inches, with parallel walls. A top of tin, six inches high, and slightly larger in diameter than the neck of the glass jar, was securely attached to it by means of plaster of Paris, followed by a mixture of rubber and resin. The tin top was painted, inside and out, with black acid-proof paint. Two nipples near the upper end of the top provide for the entrance and exit of the air. The one through which the air is aspirated is continued on the inside of the plant chamber to near the bottom. A tightly sealing friction lid allows free access to the chamber.

The plant chambers are immersed in the water of the termostats. When completely furnished for an experiment, they contain two plants, a thermometer and a Lambrecht polymeter. Readings of the temperature and relative humidity were made hourly and recorded with the hourly increments of growth.

III METHODS

1. Manipulation of the apparatus.

It is important at this point to give some details concerning the method of procedure in the use of the various parts of the apparatus. In beginning an experiment the thermostats and the plant chambers were first brought to the temperature desired. Care was exercised to give sufficient time to allow the glass walls of the plant chambers to attain the temperature of the water of the thermostats.

When working with low temperatures the water in the thermostats was first cooled with ice or snow, the thermo regulators maintaining the somewhat higher temperature desired. On cold days it was found advantageous to open the windows and thus to cool the laboratory below the temperature of the thermostat.

After the desired temperature had been attained within the plant chambers, the plants, polymeter and thermometer were placed into them and the top securely closed. The aspirators were started and the various stopcocks adjusted to get a constant and uniform flow of air.

A sufficient interval (two hours) was allowed for the plant containers, polymeter and thermometer to attain the temperature of the chamber, and for the plant to accomodate itself to the new conditions. After two hours, readings of the growth increment were started, it having been found, as will be discussed later, that this interval is sufficiently long.

The plants during the period of experimentation were grown in the dark. Light for measuring the growth increment was provided by an electric bulb immediately in front of the thermostat. The plant

never was exposed to the light for a period longer than forty seconds. Under these conditions the mais seedlings grew perfectly erect.

Readings of the growth increments were made with telescopes supplied with cross hairs. A scale graduated in half-millimeters, immediately behind the plant, permitted a ready and accurate measurement of the growth increment.

2. Preparation of the Seedlings

The plumules of Zea mais seedlings were exclusively used in these experiments. Reed's Yellow Dent, of the previous year's harvest, and grown on the Illinois Agricultural Plots, was used. The corn was of uniform good quality as shown by the high percent of germination.

The grains were soaked in water for about ten hours, and then placed in sphagnum for germination. Germination took place in a dark room in the basement of the building at a temperature varying between 27°C. and 29°C. The room was free from gas pipes.

When the seedlings had attained a sufficient size for experimentation they were transferred, on the evening previous, to a wide-mouthed bottle containing a nutrient solution. The nutrient solution was that recommended by Pfeffer, and known as Tollen's Solution. It is made up as follows:-

(a) 2.05 gr. $MgSO_4$ - - - - 35 c.c. H_2O

(b) 4 gr. $Ca(NO_3)_2$, 1 " KNO_3, 1 " KH_2PO_4 - - - - 35 c.c. H_2O

10 c.c. of (a), 35 c.c. of (b) - - - - - - - - 980 c.c. H_2O

Add a few drops of $FeCl_2$

The water of the nutrient solution had been distilled from a

block-tin still and then redistilled from hard glass. Before using, it was shaken up with a small amount of Carbon Black (G.Elf) as recommended by Schreiner and Skinner (15) to remove any trace of toxic substance which might be present. A new solution was prepared for every experiment.

The wide-mouthed bottle, of 125 c.c. capacity, was provided with a tightly fitting cork with two perforations. The roots of the seedlings were passed through the perforations in the cork, and the seedlings held in place by means of cotton. Evaporation was reduced to a minimum by a heavy coating of paraffin. The bottle was wrapped with black, opaque paper. The air within the plant chambers had a constant relative humidity of 95%.

IV POSSIBLE FACTORS OF DISTURBANCE OF GROWTH

1. Change of Medium.

Transferring the seedlings from the sphagnum to the bottle of nutrient solution necessitated a handling and a change of medium which produces a decided disturbance in the growth, as was pointed out by Askenasy (10). An interval of twelve hours, between the transfer and the reading of the growth increment, however, was found amply sufficient to allow the seedling to accommodate itself to the new conditions. The transfer was made rapidly and carefully so that the shock incidental to handling is reduced to a minimum. Whenever the experiment called for a marked difference btween the cultural temperature and the experimental temperature, the nutrient solution was gradually brought to the latter before the plant was placed into the plant chamber.

2. Sudden Changes of Temperature.

Very often the temperature at which the growth of the seedlings was studied was several degrees higher or lower than the temperature at which they were grown. Before proceeding it was necessary to satisfy oneself of the length of period necessary for the plant to recover from the temporary depression or acceleration incident to the change in temperature.

A number of investigators have studied the effects of sudden changes of temperature on plant growth. One of the first to take up the problem was Koeppen (3). He came to the conclusion that an abrupt change of temperature, from lower to higher or vice versa, brought about a reduction in growth. He maintained that it is the sudden change rather than the temperature that affects the growth.

Pedersen (13) in 1874 repeated the above experiments and ob-

tained results diametrically opposed to the generalizations of Koeppen. He found that by exposing roots of seedlings of Vicia faba to sudden and to gradual changes of temperature between 10° and 20° R., no evidence of any retardation of growth was manifested. He found that the growth-rate depended solely on the absolute temperature, the act of change being without influence.

In 1890 the problem again was taken up by Askenasy (10). His observations were confined to the roots of mais. He found that the influence due to a sudden change of temperature depended on whether the temperature from which the transfer is made lies above or below the minimum temperature for growth. When the minimum temperature used still permitted growth a change to the higher temperature was followed by an immediate ressumption of the rate of growth characteristic for the higher temperature. When, however, the minimum temperature was near the zero point, the transfer to a higher temperature was followed by a more or less tardy resumption of the normal growth-rate.

In 1894 True (12), in Pfeffer's laboratory, obtained results which confirm those of Askenasy. He found that the effect of a sudden change of temperature depends upon "the position of the lower limit". True concludes as follows:- "Following a sudden fall or a sudden rise of the temperature between 18°- 21°C. and 0.5°- 1.5°C. as extremes, the first effect seen is a slight turgor-change due to physical causes, producing, or tending to produce, a shortening in length if the temperature be lowered; or in case the temperature be raised, producing an elongation. Following this mechanical action a period of depressed growth usually follows. The duration of the depression-period depends on the position of the lower temperature

limit and on the length of time of exposure to this temperature."

If higher temperatures are used he finds that "every change from 30° to 18°C. is followed by a reduction of the growth-rate during the ensuing one-fourth hour. Further effects plainly due to the change are not to be traced in the later growth. It increases or diminishes according to the internal conditions prevailing. The transfer from 18° to 30°C. is always followed by an increased amount of elongation during the ensuing fifteen minutes. As before, the growth-rate gives no further evidence of being influenced by the temperature-change. In both cases, the traceable effects of the change disappear within fifteen minutes".

Before proceeding with the study of the relation of temperature to growth it was deemed necessary to repeat some of the experiments on the effects of sudden changes of temperature on growth, especially in so far as this affects the problem under consideration.

The following results show the influence of a sudden change of temperature of five degrees on the rate of growth of mais seedlings. The temperature was kept constant at 25°C. for six hours and then raised, within five minutes, to 30°C.

TABLE A

Showing Effect of a Sudden Change

of Temperature.

Temperature changed in 5 minutes*

	Temp. 25°C.						Temp. 30°C.				
Hr	1	2	3	4	5	6	7	8	9	10	11
1	50	25	75	75	50	50	75	100	100	100	100
2	25	50	75	75	50	75	125	125	100	100	100
3	75	75	75	75	100	100	125	175	150	125	175
4	25	50	75	75	75	75	75	150	150	125	150
5	50	50	50	75	75	75	100	150	125	100	100
6	75	50	50	75	50	75	75	150	100	75	75
7	75	75	50	50	75	75	75	150	125	100	100
8	50	75	75	50	75	75	100	125	125	125	100
9	50	50	50	75	100	100	100	150	125	100	75
Ave	53	55	64	69	72	78	94	142	122	105	108

* The numbers represent hundredths of a millimeter. The decimal point has been omitted for convenience.

The results, as given in table A, show that the rate of growth was increased markedly during the second and third hours, after the change of temperature. This result differs somewhat from the conclusions of True and Askenasy. True found that the growth rate responded rapidly and with an increased rate to a change of temperature. The rate of growth rising above that of the normal rate for that temperature, but very soon (15 minutes) returning to the normal rate of growth for the new temperature. The essential difference in the results of True and my own lies in the longer period required by the plant to resume the rate characteristic of the new temperature. This difference may be accounted for by the difference in method of changing the temperature. Since my plants were grown in bottles containing nutrient solution in plant chambers of constant temperature and humidity, the temperature of the bath and chamber could be suddenly (in less than 5 minutes) raised the five degrees, but the nutrient solution, in which the plants were growing only slowly assumed the new temperature. The nutrient solution, however, assumed the new temperature in considerable less than two hours, and since the readings of the growth increment were not recorded until after a lapse of two hours, my data are free from any error incident to a transfer from one temperature to another.

Since it was my object to study the growth rate at temperatures higher as well as lower than the temperature at which the seedling was grown, a further series of experiments as follows was undertaken. Two lots of seedlings were grown at 20°C. and 29°C. respectively. A number from each lot was placed in the plant chambers at 25°C. and the increments of growth measured. The results are tabulated in table B.

TABLE B

Showing Effect of a Sudden Change of Temperature.

Seedlings grown at 29°C.

Hr	1	2	3	4	5	6	7
1	25	50	50	50	75	75	75
2	25	75	50	75	50	75	100
3	50	75	75	75	75	100	100
4	25	75	75	75	100	100	75
Ave	31	69	62	69	75	87	87

Seedlings grown at 25°C.

Hr	1	2	3	4	5	6	7
1	75	50	75	75	75	75	100
2	100	75	75	75	50	75	75
3	100	50	50	75	75	75	75
4	125	100	75	75	75	75	50
Ave	100	69	68	75	69	75	75

An inspection of the results shows that, for the first hour, the seedlings grown at 20°C. responded by an increased rate of growth, while those grown at 29°C. show a decreased rate. After the first hour, however, the normal growth, characteristic for 25°C. is resumed by both series of seedlings.

We may therefore conclude that after one hour the plants have become adapted to the new conditions, and that my readings of the increment of growth are characteristic of the prevailing temperature.

V NORMAL GROWTH

In experimental work involving a large number of different individual plants the amount of variation, functional and otherwise, is often very great. To reduce this to a minimum, plants from the same progeny, as far as possible, were used. In the several series of experiments here recorded, the individuals under experiment were taken from a single ear of corn, of which the tips and butts were rejected.

Even when these precautions are taken there is still considerable individual variation in the average rates of growth. Occasionally a seedling is found whose rate of growth is far above or far below the average, and to include such in a general consideration of normal growth would greatly change the averages obtained from a considerable number of seedlings whose rate of growth is quite different but rather uniform. Askenasy (10), in his studies on the relation between growth and temperature says:- "Es ist sehr wichtig, bei vergleichenden Versuchen nur mit gesunden Wurzeln zu arbeiten. Das einzige sichere zeichen der Gesundheit einer Wurzel ist ein entsprechendes Wachsthum. Ich habe darum immer das Wachsthum der

Wurzeln erst eine Zeit lang bei einer dem Optimum nahen Temperatur ($26-29^{\circ}$) beobachtet und alle Wurzeln, die unter 1.7 mm. stündlichen Zuwachs zeigten, verworfen. Pedersen bemerkt allerdings, 'dass es nicht erlaubt wäre, jede langsam wachsende Wurzel als krank und abnorm zu betrachten, bloss deshalb weil sie langsam wächst'. Ich bin aber anderer Ansicht. Viele Umstände, die auf das Wachsthum der Wurzeln ungünstig einwirken, sind uns nicht genügend bekannt, wir nehmen sie nur an ihren Folgen wahr, und wir werden sicherer gehen, wenn wir abnorm langsam wachsende Wurzeln verwerfen." (p.63).

True (12) in his work evidently eliminated the plants showing an abnormally rapid or slow growth. He states:- "In the investigation only those specimens were used which, by at least an average growth, indicated a normal condition" (p.368).

The seedlings used in the present studies were grown from selected ears and, so far as possible, those of each series were from grains taken from the same ear. They were grown under identical conditions and only those of the same age and approximately the same height were chosen (16). All seedlings whose plumule was more than twelve and less than ten millimeters in length were rejected. Finally, the seedlings, before they were placed in the plant chambers, were grown in nutrient solution for from eight to ten hours at nearly the optimum temperature ($27-29^{\circ}$) and the growth-rate noted. All seedlings whose growth-rate deviated widely from the average were rejected.

VI RESULTS OF EXPERIMENTS

1. The rate of growth for a twelve-hour period, for the temperatures 12--43°C.

In all the experiments excepting those dealing with temperatures near the minimum and maximum, readings of the growth increments were made hourly. At temperatures near the minimum and maximum the growth increment is so small that hourly measurements are made with difficulty and the error resulting is correspondingly great. Readings at these temperatures, consequently, were made at three-hour intervals. Readings at temperatures between 20° and 30° C. were continued hourly for twelve hours; at other temperatures they were continued for longer periods--twenty-one to thirty-nine hours.

The tables Numbers I to XXXVI record the results of my measurements of 430 plants, at temperatures varying from 12°C. to 43°C., and for periods from twelve to thirty-nine hours. The hourly increments of growth for temperatures between 31° and 43° are recorded in Tables II to XVI inclusive; those for temperatures between 12° and 20° in Tables XVII to XX. The record of the hourly growth increments of the large number of plants measured between the temperatures of 20° and 30°C. would greatly increase the bulk of this work and add little, if anything, for discussion. These hourly readings have, therefore, been omitted and the average hourly growth increments for a twelve-hour period computed. These have been included in Table I. In the tables that follow the figures express the growth increments in hundredths of a millimeter.

In Table I the figures under the respective temperatures repre-

sent the average hourly growth increments of individual plants for a period of twelve hours. The figures at the base of the columns represent the average hourly growth increments for a given temperature of all the plants observed. By following these figures from 12°C. upward it will be noted that the greatest average hourly growth, based on a period of twelve hours, takes place at 32°C. The optimum for the plumule of mais was found by De Caudolle (4) at 28°C., by Sachs (1) at 34°C., by Koeppen (3) at 30° and 33½°, and by Davenport (21), using Koeppen's data, at 32.4°C. Beyond 32°C. the growth increment decreases and at 43°C. averages 0.06 mm. per hour. The temperatures 12° and 43°C. are not the minimum and maximum temperatures for growth in mais seedlings.

The manner of preparation and selection of seedlings for experimentation has already been discussed. It is interesting to note that even after such preparation and selection the average hourly growth increment differs widely in different individuals. This individual variation is most marked in the seedlings subjected to temperatures below and above the optimum (32° C.).

If the growth increments as given in Table I are compared with those of Koeppen (3, p.40), a number of rather wide differences are at once apparent. It will be noted that the average hourly increment of growth as given in Table I gradually increases as the temperature rises to 32°C., and that it decreases beyond that temperature. At no time did I get the irregularities in rate of growth at successively higher temperatures as did Koeppen. A double optimum at 30° and 33½°C., obtained by Koeppen, and said by him to be due probably to "eine chemische Verbindung in einer solchen Weise dass dadurch das Wachsthum eine Verzögerung erleidet", is not in the slightest degree

indicated in my results. I am of the opinion that the irregular variation in growth-rate at different temperatures, and the double optimum are attributable to the small number of seedlings used and the method of culture employed. He says (p.13),"Die Normzahl der bei jedem Versuch angewandten Exemplare war: für Lupine, Erbse und Mais 8 (6-10), für Saubohne 5-8, für Weizen 10-15, von denen jedoch nur die Hälfte oder 3/4 Keimten".

Plate II represents the growth curve as plotted from the data given in Table I. The abscissae represent the temperatures from 12° to 43°C., and the ordinates the average hourly growth in hundredths of a millimeter. Plate III is a similar curve drawn from the data as given by Koeppen (3, p.40). The two curves in general agree in that with an increase in temperature the growth increment increases, at first slowly and then more rapidly to the optimum. Beyond the optimum temperature the growth increment decreases at first rather rapidly, then less rapidly as the maximum temperature is approached. They differ in that the curve plotted from my data is very much more regular, shows a single optimum (32°C.) instead of two (30° and 33½°C.), and that the rise toward the maximum occurs at 38°C., rather than at 36°C. (Koeppen). These slight differences probably are due to the small number of seedlings used by Koeppen, his method of culture, and his consideration of several plants whose rate of growth was far above or below the average (normal). These latter very markedly alter his results, since they are based on so small a number of plants. Thus on page 40 of Koeppen's work we find an extremely wide variation in growth, with a change in temperature of only 1/10 of one degree. This in the case of the lupine for forty-eight hours was 22.4 mm. at 28.4°C. and 50.1 mm. at 28.5°C.;

for mais 30.4 mm. at 28.4°C. and 26.5 mm. at 28.5°C.

2. Relation of the growth-rate to Van't Hoff's Law.

Van't Hoff (17) found that the rate of chemical reaction is generally doubled or trebled for every rise of ten degrees Centigrade. It has been found that the reactions of physiological processes, at medium temperatures, in both animals and plants, conform more or less closely to this law. Thus for respiration, Claussen (5) found for lupine seedlings and for Tyringa flowers, between 0° and 20°C. a coefficient of 2.5. Miss Matthaei (6) has shown that in photosynthesis the rate is increased 2.1 for cherry-laurel leaves and 2.3 for sunflower leaves, between 9° and 19°C. Balls (14) states that the law holds for the rate of growth of the Sore-shin fungus. Cohen (18) using Hertwig's data finds that it is true for the development of frog's eggs, and Herzog (19) for spore-formation in Saccharomyces pastorianus. Still other examples may be cited.

In examining the data upon which the conclusions of these authors are based we find that the law of Van't Hoff, if applicable to functional activity, is applicable only to a very limited range of temperature. A study of the results as recorded in Table I shows the following coefficients for each ten degrees Centigrade:

12°- 22°	8.4	21°- 31°	2.1
13°- 23°	7.1	22°- 32°	2.0
15°- 25°	3.9	32°- 42°	0.97
18°- 28°	3.5	33°- 43°	0.55
20°- 30°	2.4		

Between the temperatures of 22° and 32°C. (optimum) the coefficient is 2, that is, the growth-rate is just doubled. For temperatures below the optimum, the coefficient increases. This may be in-

terpreted as in accordance with the Van't Hoff law, which says that the coefficient decreases as the temperature increases. Beyond the optimum (32°C.) the coefficient is 0.97 for the ten degrees between 32° and 42°C., and 0.55 between 33° and 43°C.

The growth-rate of the mais seedling at temperatures between 12° and 43°C. accords fairly well with the Van't Hoff law between the temperatures of 15° and 32°C., approximately one-half the temperature range for growth of the mais seedling.

3. The rate of growth at temperatures 31° and 43°C. inclusive.

In Tables II to XVI the hourly increments of growth at temperatures between 31° and 43°C. are recorded. The figures at the top of each column indicate the plants growing in a plant chamber; the letters following the figures, the individual plants. Thus 1a and 1b represent two plants growing under identical conditions in the same plant chamber. The first column gives the time of the readings; the figures in the other columns express the hourly increments of growth.

Tables XXI to XXXV inclusive give the hourly average of the growth-rate of the plumule of mais, for the temperatures between 31° and 43°C., at the intervals of 3, 6, 9, 12, etc., hours. The last column gives the average growth increments of all the plants for the period indicated in the first column.

Table Number XXXVI is a summary of the average hourly growth-rate of all plants (Tables XXI to XXXV) for periods of 3, 6, 9, 12, etc., hours. It is made up of the last columns of Tables XXI to XXXV.

A careful study of the above tables shows that at high temperatures (32° and above) the rate of growth for a given temperature, at

first increases. The period during which an increase in the rate of growth at these high temperatures, occurs becomes shorter as the temperature increases (Table XXXVI). Thus at 32°C. the rate of growth increases for a period of thirty-six hours; at 33½°, thirty-three hours; at 35°, twenty-one hours; at 36°, eighteen hours; at 37°, fifteen hours; at 38°, twelve hours; at 39°, nine hours; at 40°, nine hours; at 41°, six hours; at 42°, six hours; at 43°, three hours. When seedlings are subjected to temperatures above 32°C.for long periods, the rate of growth rapidly increases during the first few hours, and then gradually decreases until the maximum is reached. For example, at 36°C. (Table XXXVI) the average hourly growth increment for the first three hours is .47 mm; for six hours, .65 mm.; for nine hours, .72 mm; for twelve hours, .74 mm.; for eighteen hours, .76 mm.; for twenty-one hours, .73 mm.; for twenty-four hours, .71 mm.; for twenty-seven hours, .70 mm.; for thirty hours, .65 mm. From the figures (Table XXXVI; also Plate III) it is perfectly apparent that while the average hourly increment of growth for a period increases, the rate of growth gradually decreases. The period of increase in rate of growth becomes shorter as the temperature rises. The time for growth to reach its maximum at a given temperature thus shifts with the temperature. This is well illustrated in Table XXXVI. The maximum growth, as correlated with time, for each temperature is here underlined and makes a remarkably uniform curve.

The above is in general conformity with laws one and three, given by Miss Mattaei (6) for the photosynthetic process at high temperatures. The results do not conform in every case to the second law of Miss Matthaei, namely, "the higher the temperature the more

rapid is the rate of falling off". (See also Blackman, 8, p.283).

Table XXXVI and Plates IV and V.

At the temperatures above 41°C. growth ceases after a relatively short period of time. Thus at 42°C. growth continues for a period of fifteen hours; at 43°C. for nine hours,--in some individual cases in even less. Plants kept at these temperatures for six hours or longer after growth has ceased are not killed; if the temperature is gradually lowered, growth is resumed.

4. The growth-rate at temperatures 12°- 20°C.

In Tables XVII to XXI inclusive are found the hourly increments of growth at the temperatures 12° to 15°C.

It was shown by Kirchner (20) in 1880 that low temperatures show, after a longer or shorter period of time, a retarding influence on growth. He says there is seen "ein allmähliches Sinken der Zuwachse innerhalf gleicher Zeiträume, welches in manchen Fällen erst nach einigen Wochen, in andern schon nach einem bis wenigen Tagen mit völligem Wachsthums-Stillstande, resp. mit dem Turgorverlust der Wurzel endigt".

Askenasy (10), working along similar lines, obtains very different results from thos of Kirchner, and concludes that the data of the latter were secured from seedlings grown under improper conditions. He says (p.73), "Anderseits geben sie (meine Tabellen) durchaus keinen Anhalt dafür, dass bei niederer Temperatur ein constantes Fallen der Zuwachsgrössen statt findet, wie dies Kirchner für den Mais (und einige andere Pflanzen) angiebt. Kirchner's Versuche erstrecken sich freilich über längere Zeiträume, mir scheint es aber als wahrscheinlich, dass die von ihm zum Theil, inbesondere auch bei Zea mais angewandte Cultur-Methode von Pflanzen auf feuchtem Fluss-

papier auf die Dauer einen ungünstigen Einfluss auf die Versuchspflanzen ausüben musste".

My own results agree with those of Askenasy. The hourly increments of growth at 12°, 13° and 14°C. were determined for twelve hours, thirty-four hours, and thirty-six hours, respectively. At none of these temperatures, for the period indicated, is a decrease in rate of growth exhibited. (See Tables XVII to XXI).

VII DISCUSSION

The curve (Plate I) plotted from the data given in Table I corresponds in general with the curves usually given. It rises gradually to a maximum which lies at 32°C., and then falls more rapidly to zero.

A study of the data, however, shows some new and important facts. The curve plotted from the growth increments for a twelve-hour period rises at first gradually and then more rapidly, to 32°C.; it then falls, at first rapidly, and then less rapidly, until the maximum temperature is reached. The curve plotted from the average increments for a six-hour period (Plate VI) shows a less rapid rise to the maximum. This is due to the fact that the seedlings subjected to temperatures between 12° and 32°C. have not yet attained the maximum hourly rate of growth for those temperatures (Table XXXVI). The position of the optimum has shifted to 31°C. Beyond this optimum temperature (31°C) the curve is less steep, falling very slowly as compared with the curve plotted from data obtained when the period of observation is twelve hours.

The curve plotted from the growth increments of a twenty-one hour period (Plate VI) drops more rapidly beyond the optimum (32°C.) than does either the one plotted from the six-hour or the twelve-hour period. This is more particularly true beyond the temperature of 40°C. It is seen that the curve beyond this temperature drops to zero, or in other words, there is no growth beyond 40°C. after a period of six hours.

The curve based on observations of a twenty-seven hour period falls rapidly beyond the optimum, and, had observations been made at

all temperatures for this period of time, there is no doubt that the curve would have dropped abruptly, similar to the one of twenty-one hours. This drop likely would have occurred somewhat sooner.

The results (Table XXXVI) bring out very clearly the importance of the time-factor in a study of the relation of growth to temperature. It is shown that at high temperatures the rate of growth is not maintained, but after a period of time decreases more or less rapidly. Since this phenomenon has an important bearing on the question of the position of the optimum we shall consider it somewhat more in detail.

Sachs (1) as early as 1863 showed that Mimosa could withstand a temperature of 50°C., or even above, for several minutes, but longer periods of time, at this temperature, were fatal.

Eidam (22) subjected Bacterium termo to a temperature of 45-47° C. for one-half to three hours and found that this produced no ill effects; when subjected, however, to this temperature for a period longer than four hours, its growth subsequently, at a lower temperature, was retarded.

Ward (23) in his studies on cell division and growth of Bacillus ramosus, in relation to temperature, says (p.446), "With high temperature cultures I never got anything like so large a crop at 30-35°C. as at 22-25°C., other things being equal. Moreover, it seems clear that though the growth may, for a short time, be as rapid as it is near the optimum, it soon slows down".

Ewart (24) in his studies of the relation of temperature to the rate of protoplasmic streaming found that at 30°C. a decrease in rate was manifested after a period of twenty minutes; at 45°C. there was a marked decrease of rate after six minutes.

Turning our attention to other physiological processes we find that in fermentation, according to Chudiakow (7), a decrease in rate is manifested at 25°C. after five hours; a more rapid decrease at 35°C. in two hours; at 40°C. the decreased rate manifests itself from the beginning of the exposure to this temperature.

In a study of photosynthesis in relation to light Pantanelli (25) found that with the higher light intensities a decrease in the photosynthetic values occurs after a period of time.

The same year (1904) Miss Matthaei (6), working on photosynthesis in leaves of the cherry laurel, found that at high temperatures the initial rate of the process decreases as the time increases, and this the more rapidly the higher the temperature.

On the basis of Miss Matthaei's results Blackman (8) has called attention to the significance of the decrease in rate of a physiological function at high temperatures. He emphasizes the importance of this in a determination of the optimum, whose position is markedly influenced by this decrease in the initial rate. I have shown in the introduction to this paper that all investigators in determining the optimum temperature for growth subjected the plant to a given temperature for a longer or shorter period of time, usually forty-eight hours, and determined the increment of growth from a single measurement taken at the end of such period. The temperature at which the greatest increment of growth was found was called the optimum. If the rate of growth at any given temperature varies with the time of exposure to that temperature it is evident that the methods heretofore used cannot show it. Readings of the growth increment must be taken at short intervals and for a sufficiently long period of time.

In my studies on growth the importance of the time-factor in relation to the position of the optimum is clearly brought out. The data of the average hourly growth increments brought together in Table XXXVI show in every case, except at 43°C., that the average hourly increment increases, at first rapidly and then more slowly, to a maximum. After the maximum growth increment is reached growth proceeds markedly slower, that is the increment per hour is less.

This condition is not quite analogous to the data given for other physiological processes at high temperatures. In photosynthesis, according to the data of Miss Matthaei, a fall in values occurs at 30.5°C., after the plant had been subjected for only $1\frac{1}{2}$--$2\frac{1}{2}$ hours to this temperature. At higher temperatures a similar, but greater fall occurs after the initial reading. It therefore is essential that, in a study of photosynthesis, the initial reading be taken, as Blackman has pointed out, after as short a preliminary time as possible.

My data show that for growth the depression in the rate at high temperatures occurs after the plant has been subjected to the given temperature for a much longer period than is the case for photosynthesis. At 31°C. the maximum growth rate is reached after thirty-nine hours; at 32°C. after thirty-six hours; at 36°C. after eighteen hours; at 40°C. after nine hours; at 43°C. after three hours. In other words the time elapsing between the subjection of the plant to the temperature and the first reading should not be longer than three hours for 43°C., and thirty-nine hours for 31°C. The time at which the retardation takes place, for each temperature between these extremes is well brought out in Table XXXVI.

The time-factor also affects the position of the optimum. Ac-

cording to the table of averages (Table I) based on observations for twelve hours, the optimum for the plumule of mais is 32°C. By extending the observations over much longer periods of time the optimum shifts from 32°C. to 31°C. (Table XXXVI).

My data (Table XXXVI) show a very rapid increase in the rate of growth for a short time after the exposure to high temperatures. This is shown especially well in the curves of Plates IV and V. The curves at first rise very suddenly; after the first three hours they rise more slowly to the maximum. This also is brought out by Ward (23) in his work with Bacillus ramosus. He says (p.446), "at the optimum it metabolises, and grows, and respires, etc., at its best; but at higher temperatures removed from that it may grow for a short time more rapidly, but soon exhausts itself, and so produces a poorer crop in the end".

The results obtained by Tamman (26) and others on the effects of high temperatures on enzyme action also agree most beautifully with the results on growth herein recorded (compare Table XXXVI).

The question arises, what shall be considered as the optimum temperature? Are we justified to say that the optimum for mais is 32°C. as is shown by the data of Table I? Here the greatest hourly average growth, based on a twelve-hour period of observation, is found to be at 32°C., while from the data in Table XXXVI, based on longer periods of observation, the greatest hourly average is found to be at 31°C. Evidently then there is no such thing as absolute optimum temperature for mais. In speaking of the optimum temperature it is necessary also to express the time.

If we regard as the optimum "the highest temperature which can be permanently sustained without depression of function" (Blackman)

then an optimum temperature for growth does not exist. If, on the other hand, we consider with Blackman as the optimum that temperature at which "the retardation produced by exposure to superoptimal temperature must not be of the nature of permanent injury, and that therefore on cooling again to the optimum temperature there must be a return of the function to its highest value", the optimum temperature for mais would lie higher than 32°C. But even in this definition of the optimum it seems that the time-factor must be considered.

In seeking for an explanation of the depression of the growth-rate at high temperatures we must still confine ourselves largely to the realm of theory. Growth is an exceedingly complex physiological process and a complete analysis of all the factors that play a part is as yet impossible. The external conditions are fairly easy of control and we know a good deal concerning each one as a limiting factor. The internal factors are not so readily controlled and our knowledge of these is very limited.

That internal factors do play the part of limiting factors is not out of question, but in no case has direct experimental proof of it been established. However, recent work in other fields gives some evidence and shows close analogies to the decrease in the growth process in plants.

Some of the most suggestive analogies are those of heat depression in animals, and the reaction of enzymes at high temperatures (See Winterstein (27), Tamman (26) and others).

VIII CONCLUSIONS

1. The conclusion of Koeppen that the curve of growth in relation to temperature shows two optima is erroneous.

2. The optimum temperature of mais, for a twelve-hour period, is 32°C.

3. The optimum temperature in the curve of growth shifts as the length of the period of observations is increased.

4. At high temperatures (31°C. and above for mais) the initial growth-rate is not maintained, but there is a falling off in the rate.

5. The decrease in the growth-rate at high temperatures makes it necessary to consider the time-factor in determining the position of the optimum of growth.

6. The curve for the rate of growth constructed from readings extending over a sufficiently long period of time, is very similar to the curve representing the activities of other functional processes.

7. At temperatures near the minimum (12--14°C.) no decrease in the growth-rate is shown.

8. The growth-rate at medium temperatures accords fairly well with Van't Hoff's Law.

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TABLE I

Averages of Growth of Plumule of Mais for 12 hours.

12°	13°	14°	15°	18°	20°	21°	22°	23°	24°	25°	26°	27°	28°
06	.08	15	16	25	52	54	54	56	62	102	66	87	102
08	08	16	20	33	45	54	70	66	54	79	83	75	102
.06	.25	15	25	35	54	52	39	54	75	66	81	81	118
08	.10	12	23	20	37	50	75	87	66	77	116	92	91
08	.19	14	19		39			46	83	83	114	63	106
08	.08	23	21		31			58	83	73	87	98	98
			16		48			73	69	71	79	79	89
			19		46			77	56	83	83	81	106
			19		54			75	63	64	81	130	93
			23		44			54	91	70	66	118	104
					41			64	56	62	65		95
					50			58		68	85		104
											79		81
											66		96
											75		79
													87
													87
													98
													83
													100
													129
													96
													100
													116
.07	.09	17	19	28	45	52	59	64	69	75	82	90	98

TABLE I
(continued)

29°	30°	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°	42°	43°
120	98	118	112	81	89	118	79	54	54	44	31	15	.08
88	104	100	92	94	100	83	133	52	62	69	35	10	12
129	100	116	106	98	94	104	79	69	77	52	31	10	12
110	112	100	133	100	62	118	79	56	52	46	31	10	14
87	100	114	108	91	110	96	87	75	52	35	29	.08	.06
133	100	118	108	116	102	96	92	62	60	56	35	12	12
112	144	123	108	83	75	48	77	79	60	54	29		
98	104	110	104	104	133	69	73	65	50	45	29		
87	112	116	137	88	119	89	79	73		41			
94		106	135	108	108	89	60	77		44			
96		104	104	110	77	64	87	96		66			
		116	90	96	94	77	81	87		58			
			108	96	129	96							
			106	108	110	100							
			81	141	91	106							
			135	112	62	116							
			100	96	98								
			137	189	104								
			150	116	104								
			110	96	146								
			92	108	148								
			120	127	112								
			137	129	141								
			106	94	141								
			116	150									
			110	94									
			123	129									
			106	96									
				131									
				100									
105	108	111	113	109	106	97	84	70	58	50	31	11	.06

TABLE II

Increments of Growth for 39 hours

31° C.

	1a	1b	2a	2b	3a	3b
10:00 AM	700	750	1325	1625	950	1000
11:00 "	725	800	1450	1675	1000	1025
12:00 M	750	850	1500	1775	1075	1075
1:00 PM	825	950	1600	1850	1200	1175
2:00 "	950	1050	1700	1950	1300	1275
3:00 "	1100	1150	1800	2125	1450	1400
4:00 "	1200	1250	1900	2275	1550	1525
5:00 "	1350	1350	2000	2425	1675	1650
6:00 "	1500	1425	2125	2550	1750	1775
7:00 "	1600	1550	2250	2700	1875	1900
8:00 "	1750	1650	2350	2850	2000	2050
9:00 "	1900	1750	2450	3000	2100	2150
10:00 "	2050	1850	2600	3225	2250	2300
11:00 "	2175	1950	2675	3425	2350	2475
12:00 "	2300	2050	2800	3625	2500	2600
1:00 AM	2450	2200	2925	3775	2600	2750
2:00 "	2600	2300	3000	3925	2700	2900
3:00 "	2750	2425	3125	4075	2775	3050
4:00 "	2850	2550	3275	4300	2950	3175
5:00 "	3000	2700	3400	4450	3100	3300
6:00 "	3125	2850	3550	4600	3225	3450
7:00 "	3250	2950	3700	4800	3325	3600
8:00 "	3400	3075	3825	4975	3450	3750
9:00 "	3525	3225	3975	5150	3575	3875
10:00 "	3650	3400	4100	5300	3700	4000
11:00 "	3800	3550	4200	5450	3875	4125
12:00 M	3975	3700	4400	5600	4000	4275
1:00 PM	4150	3850	4575	5825	4150	4400
2:00 "	4300	4000	4775	6000	4300	4550
3:00 "	4450	4125	4975	6175	4425	4725
4:00 "	4600	4250	5200	6325	4550	4900
5:00 "	4750	4375	5350	6475	4675	5075
6:00 "	4900	4525	5500	6625	4775	5225
7:00 "	5050	4650	5675	6800	4900	5350
8:00 "	5200	4775	5850	6950	5025	5500
9:00 "	5350	4950	6000	7125	5150	5650
10:00 "	5500	5100	6125	7325	5300	5800
1:00 AM	5900	5550	6500	7750	5700	6225

TABLE III

Increments of Growth for 21 hours

32°C.

	1a	1b	2a	2b	3a	3b	4a	5a	5b	6a
10 AM	875	525	1275	1225	1050	750	750	1050	1150	1000
11 "	950	600	1375	1325	1125	800	825	1100	1175	1025
12 M	1025	675	1500	1450	1200	850	900	1150	1225	1100
1 PM	1100	775	1600	1575	1275	900	950	1200	1275	1250
2 "	1200	875	1725	1750	1375	975	1050	1250	1350	1375
3 "	1300	950	1875	1900	1475	1050	1150	1350	1450	1500
4 "	1400	1050	2000	2050	1600	1175	1275	1450	1525	1650
5 "	1550	1200	2175	2200	1700	1300	1425	1625	1625	1825
6 "	1650	1300	2300	2325	1800	1400	1525	1750	1700	1975
7 "	1775	1375	2475	2450	1925	1475	1650	1900	1800	2125
8 "	1900	1500	2625	2550	2075	1600	1800	2050	1900	2300
9 "	2025	1600	2775	2700	2175	1725	1900	2200	2000	2475
10 "	2175	1750	2925	2825	2300	1825	2050	2325	2125	2625
11 "	2300	1850	3075	3000	2425	1975	2200	2450	2250	2775
12 "	2450	1950	3200	3150	2525	2050	2300	2600	2400	2950
1 AM	2575	2075	3300	3300	2600	2200	2450	2750	2550	3100
2 "	2700	2200	3450	3425	2725	2350	2575	2900	2700	3300
3 "	2850	2300	3600	3550	2825	2500	2700	3025	3825	3450
4 "	2950	2400	3725	3675	2900	2650	2850	3175	3000	3600
5 "	3100	2550	3850	3750	3050	2825	3000	3325	3150	3775
6 "	3225	2625	3975	3900	3200	2975	3125	3450	3325	3900
7 "	3350	2725	4075	3975	3300	3100	3275	3550	3475	4025

TABLE IV

Increments of Growth for 39 hours
32°C.

	1a	1b	2a	2b	3a	3b
10:00 AM	550	700	200	250	100	50
11:00 "	625	775	275	325	150	125
12:00 M	700	850	350	400	225	200
1:00 PM	775	925	450	475	300	300
2:00 "	875	1000	550	575	400	425
3:00 "	1000	1100	650	675	475	550
4:00 "	1150	1225	750	800	575	675
5:00 "	1250	1325	850	925	675	825
6:00 "	1375	1450	975	1050	775	975
7:00 "	1500	1575	1100	1150	875	1125
8:00 "	1625	1700	1225	1250	1000	1275
9:00 "	1750	1850	1375	1375	1175	1450
10:00 "	1875	2000	1525	1500	1350	1575
11:00 "	2000	2150	1650	1650	1475	1725
12:00 "	2150	2300	1800	1800	1600	1850
1:00 AM	2275	2450	1950	1900	1750	1975
2:00 "	2400	2600	2100	2050	1925	2100
3:00 "	2525	2725	2250	2200	2100	2250
4:00 "	2650	2850	2400	2375	2250	2375
5:00 "	2775	2975	2525	2525	2400	2500
6:00 "	2925	3100	2650	2675	2550	2625
7:00 "	3050	3250	2775	2850	2675	2775
10:00 "	3500	3650	3225	3300	3100	3200
1:00 PM	3950	4100	3650	3725	3500	3625
4:00 "	4350	4500	4025	4125	3925	4050
7:00 "	4750	4900	4450	4525	4375	4475
10:00 "	5200	5400	4850	4975	4725	4850
1:00 AM	5600	5800	5100	5300	5000	5225

TABLE V

Increments of Growth for 21 hours

$33^{o}C$.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
10 AM	750	925	1100	850	1400	1000	1200	1050	1300	1050	1075	950
11 "	800	975	1150	925	1475	1100	1275	1075	1350	1100	1125	1000
12 M	875	1050	1250	1000	1550	1150	1350	1125	1400	1150	1175	1025
1 PM	975	1175	1325	1100	1625	1175	1450	1200	1450	1250	1275	1100
2 "	1075	1250	1400	1175	1750	1250	1550	1275	1575	1350	1375	1175
3 "	1150	1350	1475	1275	1825	1350	1650	1375	1650	1450	1500	1275
4 "	1250	1450	1575	1400	1950	1500	1750	1475	1750	1575	1625	1375
5 "	1350	1550	1700	1600	2050	1600	1900	1575	1850	1675	1750	1475
6 "	1475	1650	1775	1700	2150	1725	2025	1700	1950	1800	1875	1575
7 "	1600	1750	1900	1825	2275	1850	2150	1825	2075	1950	2000	1725
8 "	1700	1875	2000	1975	2400	1950	2275	1925	2175	2075	2150	1850
9 "	1800	2000	2100	2100	2500	2050	2375	2025	2300	2200	2275	1950
10 "	1925	2125	2200	2250	2650	2150	2500	2150	2450	2350	2400	2075
11 "	2025	2250	2350	2425	2800	2250	2600	2275	2600	2475	2550	2200
12 "	2125	2350	2475	2600	2975	2350	2725	2375	2750	2600	2675	2350
1 AM	2250	2475	2600	2850	3150	2475	2850	2475	2875	2750	2800	2500
2 "	2375	2600	2700	3000	3325	2575	2975	2600	3000	2875	2925	2650
3 "	2475	2725	2825	3175	3500	2775	3100	2700	3150	3000	3050	2800
4 "	2575	2850	2900	3250	3650	2825	3250	2800	3275	3150	3175	2900
5 "	2700	3000	3025	3475	3850	2950	3375	2925	3400	3275	3275	3050
6- "	2800	3100	3150	3600	4000	3075	3575	3050	3525	3400	3400	3200
7 "	2900	3200	3250	3750	4150	3200	3675	3150	3650	3525	3550	3300

TABLE VI

Increments of Growth for 36 hours

$33\frac{1}{2}^{\circ}C.$

	1a	1b	2a	2b	3a	3b
10:00 AM	975	900	1350	1250	350	400
11:00 "	1000	975	1400	1275	375	475
12:00 M	1050	1075	1475	1300	425	575
1:00 PM	1150	1175	1550	1375	500	675
2:00 "	1200	1275	1625	1425	550	750
3:00 "	1300	1400	1725	1475	600	875
4:00 "	1400	1500	1825	1525	650	1000
5:00 "	1475	1625	1925	1575	725	1125
6:00 "	1550	1750	2050	1675	800	1225
7:00 "	1650	1900	2225	1775	900	1400
8:00 "	1700	1975	2375	1825	975	1525
9:00 "	1800	2100	2525	1925	1050	1650
10:00 "	1850	2200	2700	2000	1125	1800
11:00 "	1975	2325	2900	2100	1250	2000
12:00 "	2025	2400	3025	2200	1325	2125
1:00 AM	2125	2475	3200	2275	1400	2275
2:00 "	2200	2600	3350	2375	1525	2475
3:00 "	2275	2675	3475	2450	1600	2625
4:00 "	2400	2750	3650	2575	1725	2825
5:00 "	2475	2850	3775	2675	1850	3000
6:00 "	2625	2950	3875	2775	1975	3200
7:00 "	2700	3000	4000	2850	2150	3400
10:00 "	3025	3325	4425	3200	2625	3975
11:00 "	3250	3425	4575	3300	2775	4150
12:00 M	3375	3500	4725	3500		
1:00 PM	3425	3575	4825	3550	3150	4650
2:00 "	3550	3650	4825	3650	3250	4875
3:00 "	3650	3750	4925	3750	3350	5025
4:00 "	3725	3825	5125	3900	3550	5200
5:00 "	3775	3900	5200	4025	3650	5300
6:00 "	3900	3975	5275	4075	3700	5450
7:00 "	4050#	4050	5375	4200	3900	5575
8:00 "	4100	4125	5475	4225	3950	5650
10:00 "	4275	4200	5650	4525	4100	5925

Coleoptile opened

TABLE VII

Increments of Growth for 21 hours

$34^{o}C.$

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
10 AM	900	950	1225	1300	1175	1025	900	1025	1425	1325	600	700
11 "	1000	975	1300	1375	1200	1100	925	1100	1500	1350	650	775
12 M	1000	1000	1350	1400	1250	1150	975	1225	1575	1400	700	800
1 PM	1025	1075	1400	1425	1400	1225	1025	1325	1650	1500	750	875
2 "	1075	1175	1500	1475	1500	1300	1075	1425	1750	1600	825	975
3 "	1175	1275	1600	1500	1650	1425	1175	1525	1875	1700	925	1050
4 "	1300	1400	1700	1550	1750	1525	1250	1625	2000	1825	1000	1150
5 "	1425	1500	1825	1625	1875	1675	1375	1800	2150	1975	1075	1275
6 "	1525	1600	1925	1700	2000	1775	1450	1975	2300	2100	1175	1400
7 "	1625	1725	2000	1775	2150	1875	1550	2125	2450	2250	1250	1500
8 "	1775	1900	2150	1875	2275	2000	1625	2300	2575	2350	1350	1600
9 "	1875	2000	2250	1975	2400	2125	1775	2450	2725	2500	1425	1725
10 "	1975	2150	2350	2050	2500	2250	1800	2625	2850	2625	1525	1825
11 "	2050	2275	2475	2150	2675	2375	1950	2750	2975	2725	1600	1900
12 "	2150	2400	2550	2225	2800	2500	1975	2900	3125	2850	1675	2000
1 AM	2250	2550	2625	2325	2900	2625	2100	3050	3225	3000	1750	2100
2 "	2400	2700	2725	2450	3100	2775	2175	3225	3350	3175	1825	2200
3 "	2525	2875	2825	2575	3200	2900	2300	3375	3475	3325	1950	2300
4 "	2650	3000	2875	2675	3350	3000	2400	3500	3625	3450	2025	2375
5 "	2800	3150	3000	2825	3475	3175	3550	3650	3775	3600	2175	2475
6 "	2975	3300	3150	2950	3650	3300	2650	3775	3875	3775	2250	2550
7 "	3075	3450	3175	3050	3750	3400	2750	3850	4000	3900	2300	2625

TABLE VIII

Increments of Growth for 21 hours

35°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
10 AM	675	650	1300	1675	900	925	1250	1200	800	1050
11 AM	700	700	1350	1725	925	950	1300	1250	850	1100
12 M	750	725	1400	1775	950	1000	1375	1325	900	1150
1 PM	775	800	1475	1825	1000	1075	1500	1400	1000	1275
2 "	850	875	1575	1900	1050	1150	1600	1500	1100	1375
3 "	900	925	1700	2000	1125	1250	1700	1600	1200	1500
4 "	950	1025	1800	2150	1200	1350	1800	1700	1300	1625
5 "	1050	1100	1900	2300	1300	1450	1925	1850	1450	1775
6 "	1100	1175	2000	2400	1350	1550	2000	1950	1550	1900
7 "	1150	1275	2100	2500	1425	1650	2125	2075	1675	2050
8 "	1175	1350	2175	2575	1525	1750	2200	2175	1800	2150
9 "	1200	1400	2275	2675	1600	1850	2325	2300	1950	2325
10 "	1250	1475	2375	2750	1675	1950	2400	2400	2075	2450
11 "	1275	1550	2475	2850	1750	2050	2500	2525	2175	2600
12 "	1300	1625	2575	3025	1850	2150	2600	2650	2300	2750
1 AM	1350	1700	2700	3125	1950	2300	2700	2800	2400	2900
2 "	1400	1775	2800	3200	2050	2425	2800	2950	2500	3025
3 "	1450	1850	2900	3275	2150	2550	2900	3075	2650	3175
4 "	1475	1925	2975	3350	2250	2650	3025	3200	2775	3350
5 "	1525	2000	3050	3425	2325	2775	3125	3300	2850	3450
6 "	1575	2050	3125	3500	2400	2925	3225	3400	2950	3550
7 "	1625	2150	3225	3600	2475	3050	3300	3500	3050	3675

TABLE IX

Increments of Growth for 31 hours

$36^{o}C.$

	1a	1b	2a	2b	3a	3b
10:00 AM	800	1000	1250	1150	575	650
11:00 "	850	1025	1275	1175	600	675
12:00 M	900	1075	1350	1225	675	700
1:00 PM	1000	1125	1450	1250	750	750
2:00 "	1075	1200	1500	1325	875	825
3:00 "	1175	1250	1550	1375	975	925
4:00 "	1225	1325	1650	1425	1100	1050
5:00 "	1300	1400	1750	1525	1175	1125
6:00 "	1375	1475	1850	1625	1275	1225
7:00 "	1450	1575	1950	1675	1375	1325
8:00 "	1550	1675	2050	1775		
9:00 "	1650	1775	2100	1825		
10:00 "	1725	1850	2200	1875	1600	1575
11:00 "	1775	1950	2275	1950		
12:00 "	1875	2050	2350	2050		
1:00 AM	1975	2175	2500	2150	1750	1725
2:00 "	2025	2275	2550	2200		
3:00 "	2050	2375	2675	2250		
4:00 "	2075	2450	2725	2350	1975	2025
5:00 "	2125	2550	2800	2400		
6:00 "	2150	2650	2875	2450		
7:00 "	2200	2675	2950	2500	2200	2150
10:00 "	2325	2975	3150	2700	2325	2325
1:00 PM	2400	3075	3300	2800	2575	2575
5:00 "	2450	3125	3500	3025	2775	2800

TABLE X

Increments of Growth for 21 hours

37°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
10 AM	850	725	1475	1450	1050	700	925	875	1250	1275	900	675
11 "	900	775	1550	1500	1125	750	950	950	1275	1350		
12 M	950	825	1575	1550	1175	800	1000	1000	1325	1400	1000	725
1 PM	975	850	1600	1575	1275	875	1100	1075	1375	1500	1125	800
2 "	1050	925	1675	1650	1350	950	1175	1175	1425	1600		
3 "	1125	950	1750	1700	1425	1000	1300	1250	1500	1675		
4 "	1175	1000	1850	1750	1550	1075	1350	1325	1575	1775	1450	1125
5 "	1225	1025	1900	1825	1600	1125	1425	1375	1675	1850		
6 "	1275	1075	1975	1900	1650	1200	1525	1425	1750	1925		
7 "	1350	1175	2075	1975	1725	1250		1500	1800	1975	1775	1475
8 "	1400	1225	2150	2025	1800	1300	1700	1575	1925	2050		
9 "	1425	1375	2250	2075	1825	1375	1825	1625	2025	2125		
10 "	1500	1350	2300	2125	1900	1450	1875	1650	2125	2200	2050	1850
11 "	1550	1425	2375	2175	1950	1525	1950	1750	2250	2300		
12 "	1600	1450	2425	2250	2000	1575	2075	1825	2350	2400		
1 AM	1650	1500	2500	2325	2050	1600	2150	1875	2425	2450	2325	2300
2 "							2250	1950	2525	2550		
3 "							2325	2o5o	2625	2625		
4 "	1800	1600	2650	2450	2200	1675	2400	2125	2650	2675	2600	2500
5 "							2500	2200	2750	2750		
6 "							2575	2275	2800	2825		
7 "	1900	1700	2825	2550	2350	1750	2650	2325	2850	2875	2850	2750

TABLE XI

Increments of Growth for 21 hours

38°C.

	1a	1b	2a	2b	3a	3b	4a	4b
10 AM	650	700	1100	1150	875	850	1275	1575
11 "	675	725	1125	1175	900	875	1300	1600
12 M	700	775	1150	1225	925	900	1350	1650
1 PM	725	800	1175	1250	950	925	1375	1725
2 "	750	850	1275	1300	1000	950	1450	1800
3 "	800	900	1350	1350	1075	1050	1500	1850
4 "	850	1000	1425	1425	1100	1125	1550	1900
5 "	950	1100	1500	1475	1175	1200	1625	1950
6 "	1000	1150	1575	1525	1275	1250	1700	2000
7 "	1100	1225	1675	1600	1350	1375	1800	2025
8 "	1175	1300	1750	1650	1425	1425	1875	2075
9 "	1250	1375	1825	1700	1475	1500	1925	2100
10 "	1300	1450	1925	1775	1525	1575	2000	2150
11 "	1350	1500	2000	1825	1575	1650	2050	2200
12 M	1400	1550	2075	1875	1625	1700	2125	2225
1 AM	1450	1600	2125	1925	1675	1750	2225	2300
2 "	1500	1700	2225	2000	1750	1800	2300	2325
3 "	1575	1725	2275	2050	1775	1850	2375	2350
4 "	1625	1775	2325	2100	1825	1900	2400	2375
5 "					1850	1975	2475	2425
6 "					1900	2025	2525	2475
7 "	1700	1850	2400	2150	1925	2050	2575	2500

TABLE XII

Increments of Growth for 21 hours

39°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
10 AM	775	1200	1150	1250	400	550	800	950	600	450	1350	1250
1 PM	850	1300	1275	1325	475	650	900	1050	700	550	1450	1350
4 "	975	1525	1425	1425	600	800	1100	1150	850	700	1700	1550
7 "	1125	1775	1575	1550	725	1025	1275	1400	975	850	1950	1750
10 "	1175	1950	1700	1650	825	1225	1450	1500	1100	975	2150	1950
1 AM	1350	2125	1800	1675	925	1400	1600	1625	1200	1100	2275	2100
4 "	1450	2300	1925	1750	1075	1525	1725	1775	1275	1225	2425	2250
7 "	1550	2375	2050	1775	1200	1625	1825	1875	1375	1325	2550	2375

TABLE XIII

Increments of Growth for 21 hours

40°C.

	1a	1b	2a	2b	3a	3b	4a	4b
10 AM	725	975	1050	800	1175	1475	650	675
1 PM	825	1050	1125	875	1250	1575	725	750
4 PM	950	1200	1250	1050	1375	1700	825	850
7 "	1050	1300	1375	1150	1475	1800	925	950
10 "	1100	1400	1425	1175	1525	1900	1000	1025
1 AM	1200	1500	1500	1275	1600	1950	1075	1075
4 "	1275	1575	1575	1325	1650	2000	1125	1150
7 "	1375	1650	1625	1375	1675	2050	1175	1175

TABLE XIV

Increments of Growth for 18 hours

$41^{\circ}C.$

	1a	1b	2a	2b	3a	3b
10:00 AM	600	850	500	825	1200	600
1:00 PM	675	900	550	875	1250	675
4:00 "	775	1000	650	975	1325	750
7:00 "	850	1050	700	1050	1375	800
10:00 "	900	1100	725	1100	1400	850
1:00 AM	950	1125	750	1150	1425	875
4:00 "	950	1125	750	1175	1425	875

TABLE XV

Increments of Growth for 21 hours

42°C.

	1a	1b	2a	2b	3a	3b
10:00 AM	1075	875	1200	1375	600	1200
1:00 PM	1100	900	1225	1400	650	1250
4:00 "	1150	950	1275	1450	675	1300
7:00 "	1200	975	1300	1475	700	1325
10:00 "	1250	1000	1325	1500	700	1350
1:00 AM	1275	1025	1350	1500	725	1375
4:00 "	1300	1025	1350	1525	750	1375
7:00 "	1325	1025	1350	1525	750	1375

TABLE XVI

Increments of Growth for 21 hours

43°C.

	1a	1b	2a	2b	3a	3b
10:00 AM	775	675	1300	1225	675	650
1:00 PM	800	725	1350	1275	700	675
4:00 "	800	775	1350	1275	700	675
7:00 "	825	775	1375	1300	700	700
10:00 "	825	800	1375	1300	725	700
1:00 AM	850	800	1375	1300	725	700
4:00 "	850	800	1375	1300	725	700
7:00 "	850	800	1375	1300	725	700

TABLE XVII

Increments of Growth for 12 hours

12°C.

	1a	1b	2a	2b	3a	3b
10:00 AM	1300	1300	850	1025	1000	1050
1:00 PM	1350	1325	875	1100	1050	1100
4:00 PM	1350	1350	900	1100	1050	1100
7:00 "	1375	1375	900	1125	1100	1150
10:00 "	1375	1400	925	1125	1100	1250

TABLE XVIII

Increments of Growth for 34 hours

13°C.

	1a	1b	2a	2b	3a	3b
10:00 AM	525	650	750	900	1450	1100
1:00 PM	550	700	775	950	1500	1150
4:00 "	575	700	800	975	1525	1150
7:00 "	600	725	825	1000	1550	1175
10:00 "	625	750	850	1025	1625	1200
1:00 AM	675	800	875	1075	1675	1250
9:00 "	775	950	975	1225	1875	1325
11:00 "	800	975	1050			1350
1:00 PM	875	1000	1050	1250	1925	1400
4:00 "	950	1050	1075	1325	2000	1425
8:00 "	1000		1150	1375	2100	1475

TABLE XIX

Increments of Growth for 23 hours

$14^{\circ}C.$

	1a	1b	2a	2b	3a	3b
10:00 AM	725	825	1175	850	1225	1300
1:00 PM	775	875	1225	900	1275	1400
4:00 "	800	900	1250	925	1300	1450
7:00 "	850	975	1300		1350	1500
10:00 "	900	1025	1350	1000	1400	1575
1:00 AM	975	1100	1400	1050	1450	1650
9:00 "	1175	1300	1600	1125	1600	1875
12:00 M	1225	1375	1700	1200	1675	1950
3:00 PM	1325	1475	1800	1250	1750	2000
6:00 "	1350	1550			1850	2100
9:00 "	1425	1650	2000	1325	1950	2200

TABLE XX

Increments of Growth for 48 Hours

15°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
10 AM	1000	725	850	1250	700	1225	850	600	1275	1425	800	775
1 PM	1050	775	900	1325	850	1350	875	650	1325	1475	825	825
4 "	1075	800	975	1350	875	1375	900	675	1350	1500	900	900
7 "	1125	900	1050	1450	950	1450	975	725	1400	1600	925	950
10 "	1200	975	1150	1525	1000	1525	1025	800	1475	1700	975	1025
1 AM	1275	1050	1225	1625	1075	1600	1125	900	1575	1800	1050	1125
2 "	1300	1075	1225	1650	1100	1625						
4 "							1225	975	1675	1900	1150	1175
11 "							1425	1175	1850	2250	1400	1450
2 PM							1525	1275	1950	2400	1475	1550
5 "							1600	1375	2050	2575	1625	
8 "							1700	1475	2175	2700	1700	1725
9:30 "							1775	1575				

7:30 PM

TABLE XXI

Averages of Total Growth Determined

At Three-Hour Intervals

31°C.

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	41	66	91	75	83	58	69
6 "	83	83	96	108	100	87	93
9 "	100	88	92	119	102	100	100
12 "	112	91	106	133	108	108	109
15 "	120	97	107	145	110	117	116
18 "	119	100	108	148	111	120	117
21 "	121	105	113	151	113	123	121
24 "	123	110	115	153	114	125	123
27 "	127	114	120	154	118	126	126
30 "	130	116	128	156	120	130	130
33 "	132	118	131	158	120	131	131
36 "	133	121	133	158	121	133	133
39 "	133	123	132	157	121	134	133

TABLE XXII

Average hourly Growth Determined

for 3, 6, 9, etc., hours

32°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	Ave
3 Hrs	75	83	108	116	75	50	66	50	41	83	74
6 "	87	87	120	137	91	71	87	66	62	108	91
9 "	100	94	133	136	97	80	100	94	72	125	103
12 "	108	102	137	133	104	89	108	106	81	135	113
15 "	113	103	135	138	103	96	113	113	93	140	115
18 "	115	104	135	136	103	105	116	118	102	144	118
21 "	117	104	133	131	107	112	120	119	110	144	120

TABLE XXIII

Average hourly Growth Determined

for 3, 6, 9, etc., hours

32°C.

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	75	75	83	75	66	75	72
6 "	100	87	91	91	79	104	92
9 "	106	97	100	100	86	119	101
12 "	111	108	110	104	104	127	111
15 "	115	117	116	110	110	128	116
18 "	117	119	122	118	119	129	120
21 "	119	121	123	124	122	129	123
24 "	123	123	126	127	125	131	125
27 "	126	126	128	128	126	132	127
30 "	127	127	128	129	127	133	128
33 "	127	127	129	129	129	134	129
36 "	129	130	129	131	128	133	130
39 "	132	130	125	129	125	132	128

TABLE XXIV

Average hourly Growth Determined

for 3, 6, 9, etc., hours

33°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	Ave
3 Hrs	75	83	75	58	81	66	50	50	66	75	83	50	68
6 "	83	87	91	83	91	91	71	75	83	79	91	71	83
9 "	94	91	97	94	105	102	86	86	94	88	108	86	94
12 "	98	100	104	96	108	110	91	96	108	92	116	94	101
15 "	100	103	116	98	110	115	95	105	113	100	133	103	107
18 "	101	107	125	101	114	116	97	109	116	100	134	108	110
21 "	102	108	130	105	118	118	100	112	118	102	138	112	113

TABLE XXV

Average hourly Growth Determined

for 3, 6, 9, etc., hours

$33\frac{1}{2}^{\circ}$C.

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	58	58	50	41	50	91	58
6 "	71	100	79	46	50	100	74
9 "	75	111	97	58	61	111	85
12 "	73	108	112	62	65	116	89
15 "	78	105	123	68	70	125	95
18 "	79	103	127	73	76	135	99
21 "	82	100	127	76	85	145	102
24 "	85	101	128	81	95	149	106
27 "	91	99	129	85	104	157	110
30 "	92	97	126	88	106	157	111
33 "	93	95	122	89	107	157	111
36 "	91	92	119	91	104	156	109

TABLE XXVI

Average hourly Growth Determined

for 3, 6, 9, etc., hours

34°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	Ave
3 Hrs	41	41	58	41	75	66	41	100	75	58	50	58	59
6 "	66	75	79	42	96	83	58	100	95	83	66	75	76
9 "	80	86	86	52	108	94	72	122	114	102	72	88	89
12 "	89	100	92	62	110	102	75	133	119	108	77	94	97
15 "	90	106	93	68	115	106	80	135	120	111	77	93	100
18 "	97	114	91	76	120	109	83	137	122	118	79	93	103
21 "	103	119	92	83	122	113	88	134	122	122	80	91	106

TABLE XXVII

Average hourly Growth Determined

for 3, 6, 9, etc., hours

35^oC.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	Ave
3 Hrs	33	50	58	50	33	50	83	66	66	75	56
6 "	46	62	83	79	50	71	91	83	83	96	74
9 "	53	69	88	91	58	81	97	97	97	111	84
12 "	48	69	89	89	64	85	96	100	106	116	86
15 "	45	70	93	96	70	91	96	106	106	123	89
18 "	44	70	93	93	75	99	98	111	109	127	92
21 "	45	71	92	92	75	101	97	109	107	125	92

TABLE XXVIII

Average hourly Growth Determined

for 3, 6, 9, etc., hours

$36^{o}C.$

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	66	41	66	33	50#	25#	47
6 "	71	54	66	46	87	66	65
9 "	72	64	77	58	88	75	72
12 "	77	70	79	60	85	77	74
15 "	78	78	83	73	78	71	76
18 "	70	80	82	67	78	76	76
21 "	66	79	81	64	77	71	73
24 "	63	78	79	64	73	69	71
27""	59	77	75	61	74	71	70
31 "	53	68	72	60	71	66	65

— 2 hours

TABLE XXIX

Average hourly Growth Determined

for 3, 6, 9, etc., hours

$37^{o}C$.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	Ave
3 Hrs	41	41	41	41	75	58	58	66	41	75	75	41	55
6 "	54	46	62	50	83	62	71	75	54	83	91	75	65
9 "	55	50	66	58	75	61	76	69	61	77	97	88	69
12 "	54	52	68	56	70	62	79	64	73	77	96	98	70
15 "	53	51	68	58	66	60	81	66	78	78	95	108	72
18 "	52	48	65	55	64	54	82	70	77	77	94	107	70
21 "	50	46	64	52	61	50	82	69	76	76	93	103	68

TABLE XXX

Average hourly Growth Determined

for 3, 6, 9, etc., hours

38°C.

	1a	1b	2a	2b	3a	3b	4a	4b	Ave
3 Hrs	25	33	25	33	25	25	33	50	31
6 "	33	50	54	46	37	46	46	54	46
9 "	50	58	64	50	53	58	58	50	55
12 "	54	63	69	52	54	60	61	48	58
15 "	53	60	68	51	53	60	63	48	57
18 "	54	59	68	52	52	58	62	44	56
21 "	50	55	62	47	50	57	62	44	53

TABLE XXXI

Average hourly Growth Determined

for 3, 6, 9, etc., hours

39°C.

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	Ave
3 Hrs	25	33	41	25	25	33	33	33	33	33	33	33	31
6 "	37	54	46	29	21	41	50	33	58	50	41	41	41
9 "	39	64	47	33	36	52	52	44	66	55	41	44	47
12 "	33	62	36	33	35	56	54	45	64	58	41	43	46
15 "	38	62	43	28	35	56	53	45	61	56	40	43	46
18 "	37	55	43	27	37	54	51	45	59	55	37	43	45
21 "	36	52	45	25	36	51	50	44	57	53	36	41	43

TABLE XXXII

Average hourly Growth Determined

for 3, 6, 9, etc., hours

40°C.

	1a	1b	2a	2b	3a	3b	4a	4b	Ave
3 Hrs	33	25	25	25	25	33	25	25	27
6 "	37	37	33	41	33	37	29	29	34
9 "	33	36	36	39	33	36	31	30	34
12 "	31	35	31	31	29	35	29	29	31
15 "	31	35	30	31	28	32	28	26	30
18 "	30	33	29	29	26	29	26	25	28
21 "	30	32	27	27	23	27	25	24	26

TABLE XXXIII

Average hourly Growth Determined

for 3, 6, 9, etc., hours

$41^{\circ}C.$

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	25	16	16	16	16	25	19
6 "	29	25	25	25	21	25	25
9 "	27	22	22	25	19	22	23
12 "	25	20	19	23	16	20	20
15 "	23	18	16	20	15	18	18
18 "	--	--	--	--	--	--	--
21 "	--	--	--	--	--	--	--

TABLE XXXIV

Average hourly Growth Determined

for 3, 6, 9, etc., hours

$42^{o}C.$

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	08	08	08	08	08	16	09
6 "	13	13	12	13	12	16	13
9 "	14	11	11	11	11	14	12
12 "	14	10	10	10	08	12	11
15 "	13	10	10	08	08	12	10
18 "	13	08	08	09	08	10	09
21 "	12	07	07	07	07	08	08

TABLE XXXV

Average hourly Growth Determined

for 3, 6, 9, etc. hours

$43^{\circ}C.$

	1a	1b	2a	2b	3a	3b	Ave
3 Hrs	08	16	16	16	08	08	12
6 "	04	16	16	08	04	04	09
9 "	05	11	08	08	03	05	07
12 "	04	10	06	06	04	04	06
15 "	05	10	05	05	03	03	05
18 "	No growth						
21 "	" "						

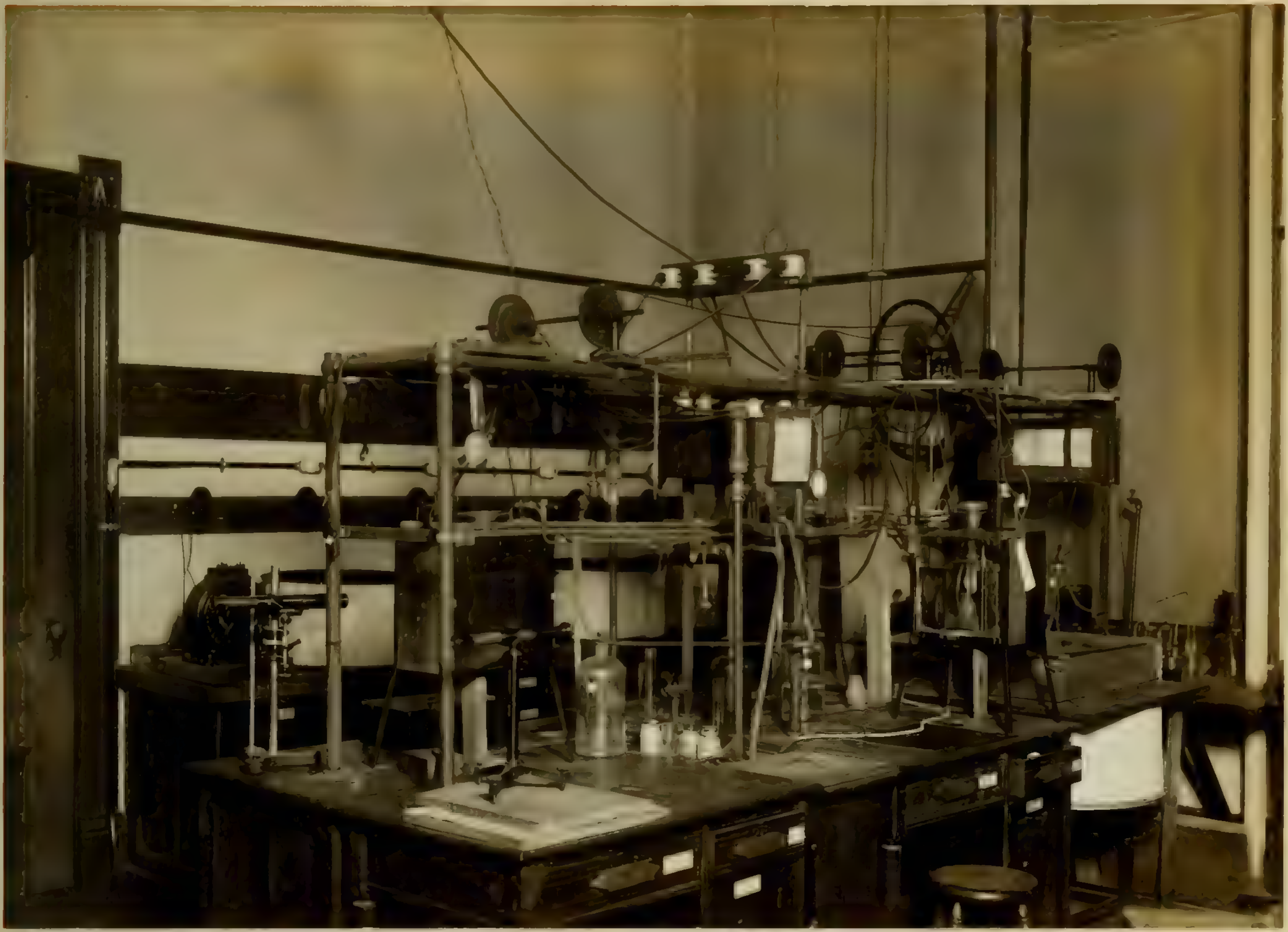
TABLE XXXVI

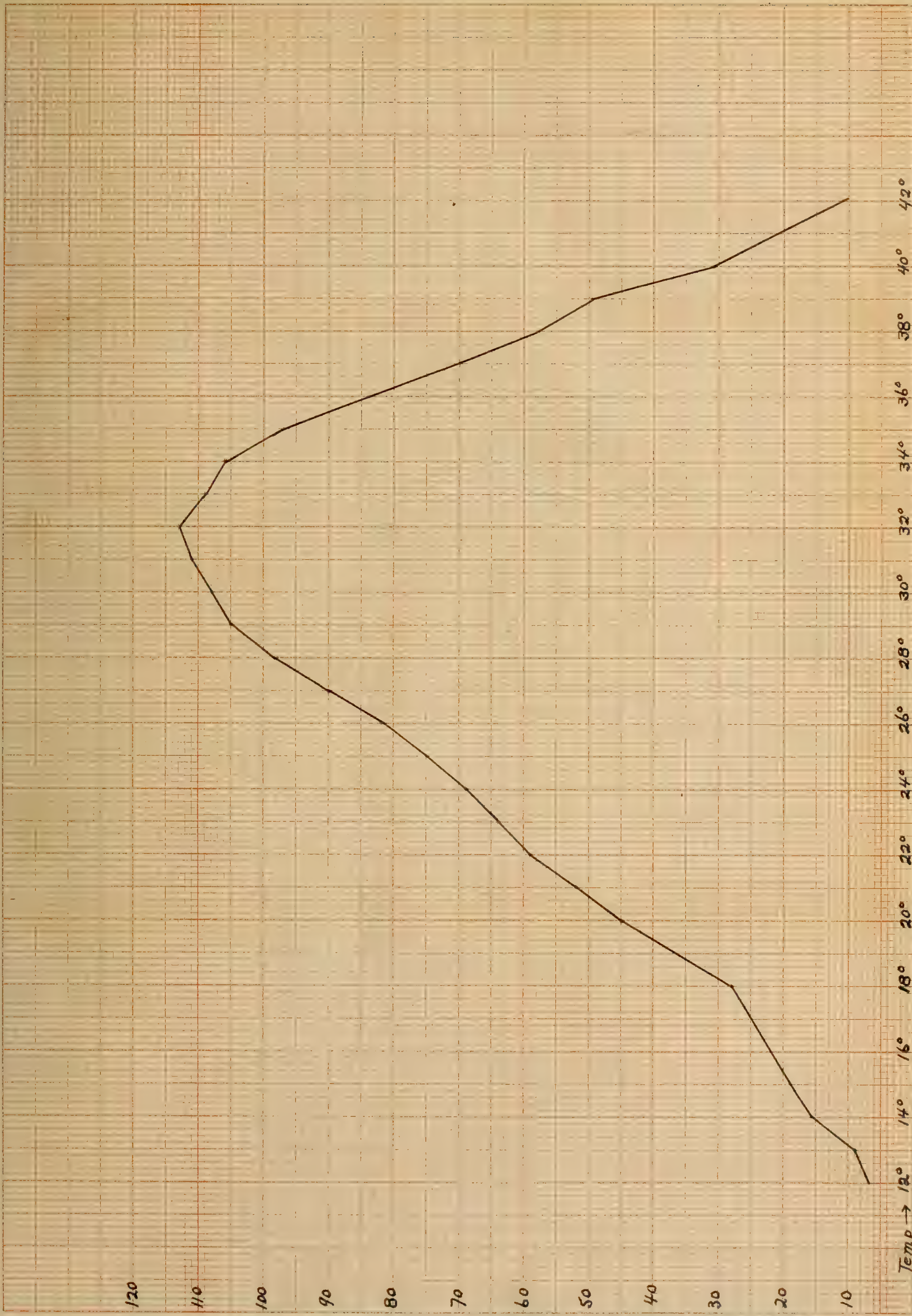
Average hourly Growth-Rate of all Plants For

Periods of 3, 6, 9, 12, etc., hours

	31°	32°	33°	33½°	34°	35°	36°	37°	38°	39°	40°	41°	42°	43°
3 Hrs	69	72	68	58	59	56	47	55	31	31	27	19	09	12
6 "	93	92	83	74	76	74	65	65	46	41	34	25	13	09
9 "	100	101	94	85	89	84	72	69	55	47	34	23	12	07
12 "	109	111	101	89	97	86	74	70	58	46	31	20	11	06
15 "	116	116	107	95	100	89	76	72	57	46	30	17	10	05
18 "	117	120	110	99	103	92	76	70	56	45	28	--	09	--
21 "	121	123	113	102	106	92	73	68	53	43	26		08	
24 "	123	125		106			71							
27 "	126	127		110			70							
30 "	130	128		111			65							
33 "	131	129		111										
36 "	133	130		109										
39 "	133	128												

PLATE I

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18°
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22°
24°
26°
28°
30°
32°
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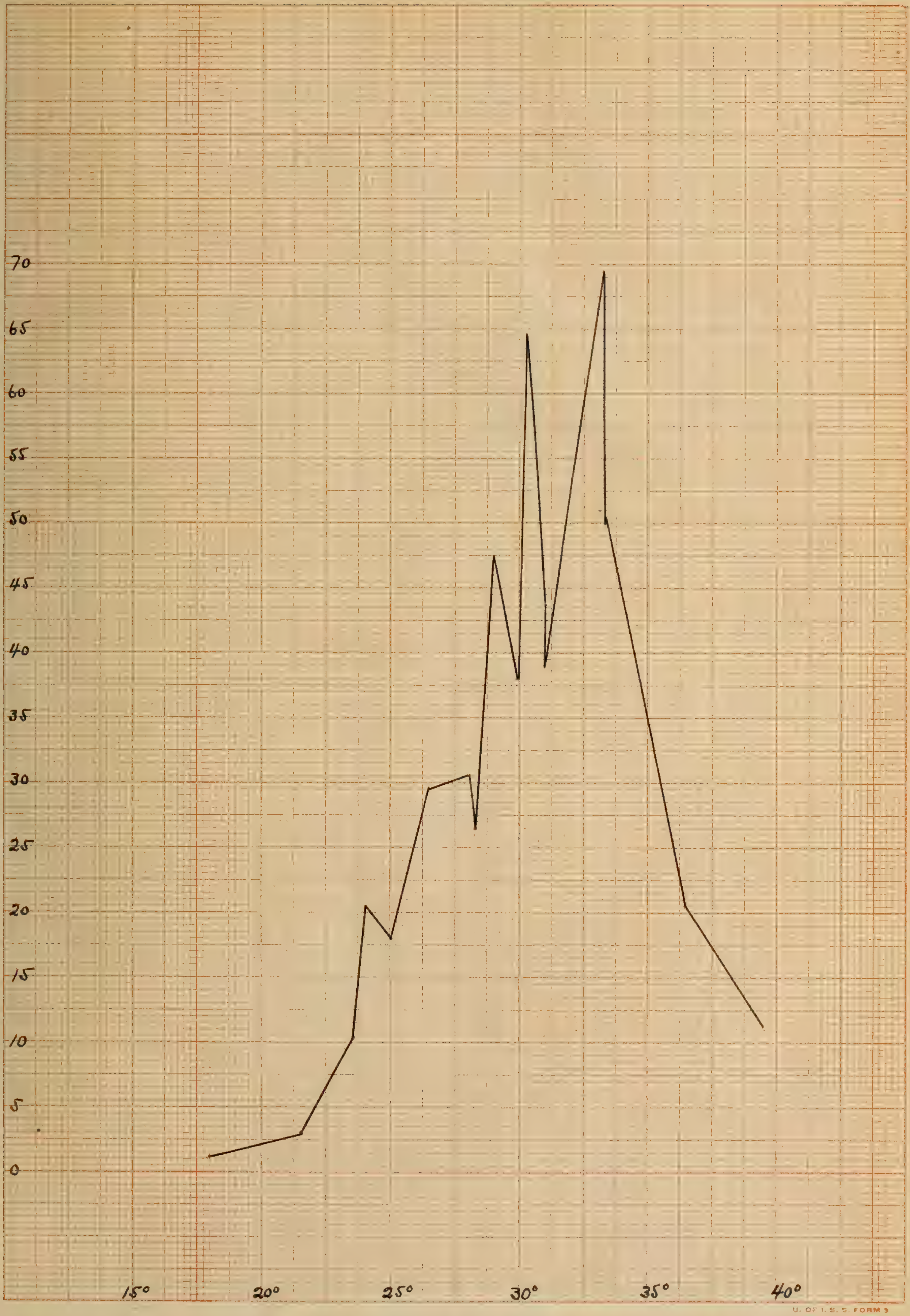
36°
38°
40°
42°
120
110
100
90
80
70
60
50
40
30
20
10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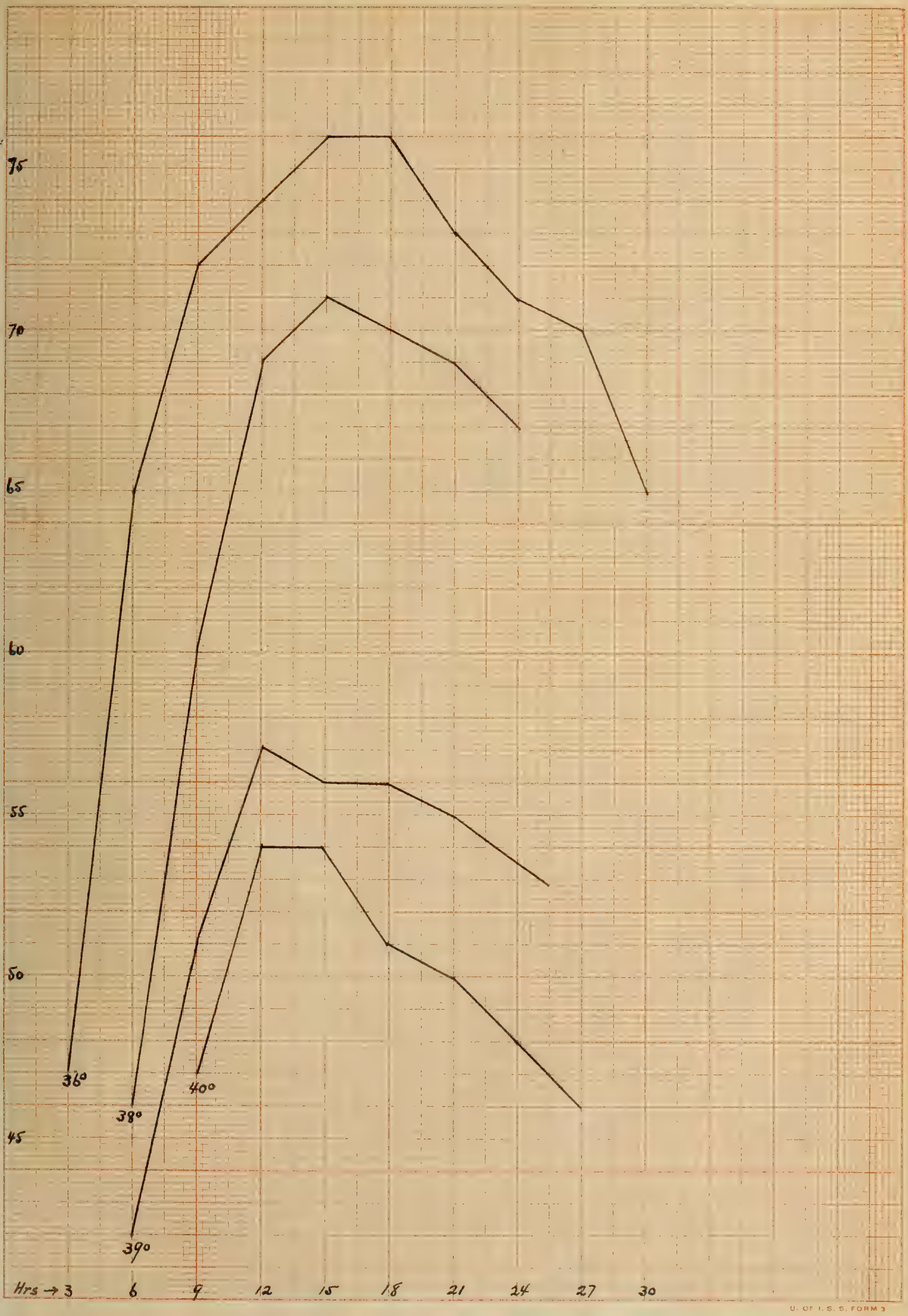
U. OF I. S. S. FORM 3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65
60
55
50
45
36°
38°
39°
40°
Hrs → 3
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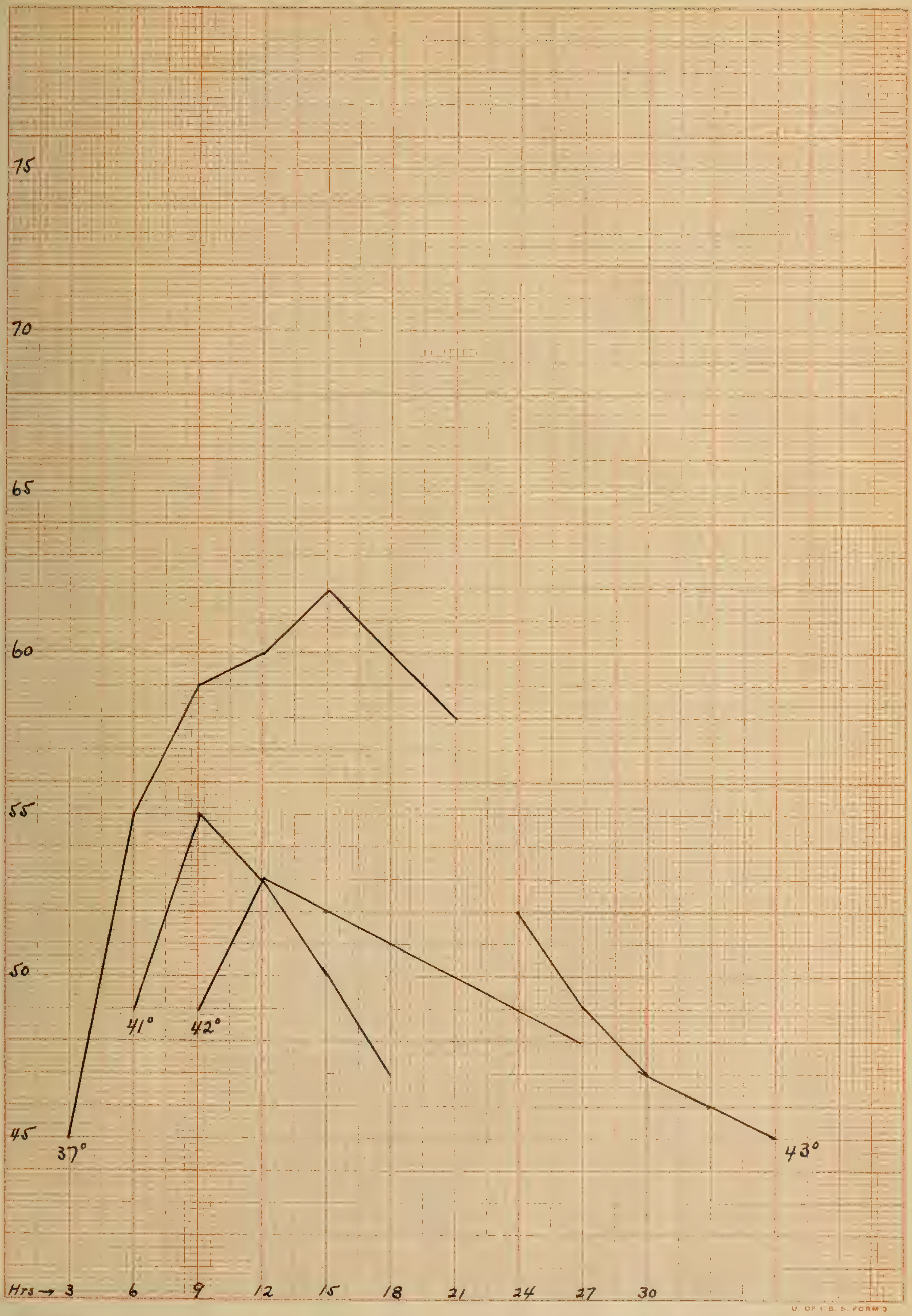
9
12
15
18
21
24
27
30
U. OF I. S. S. FORM 3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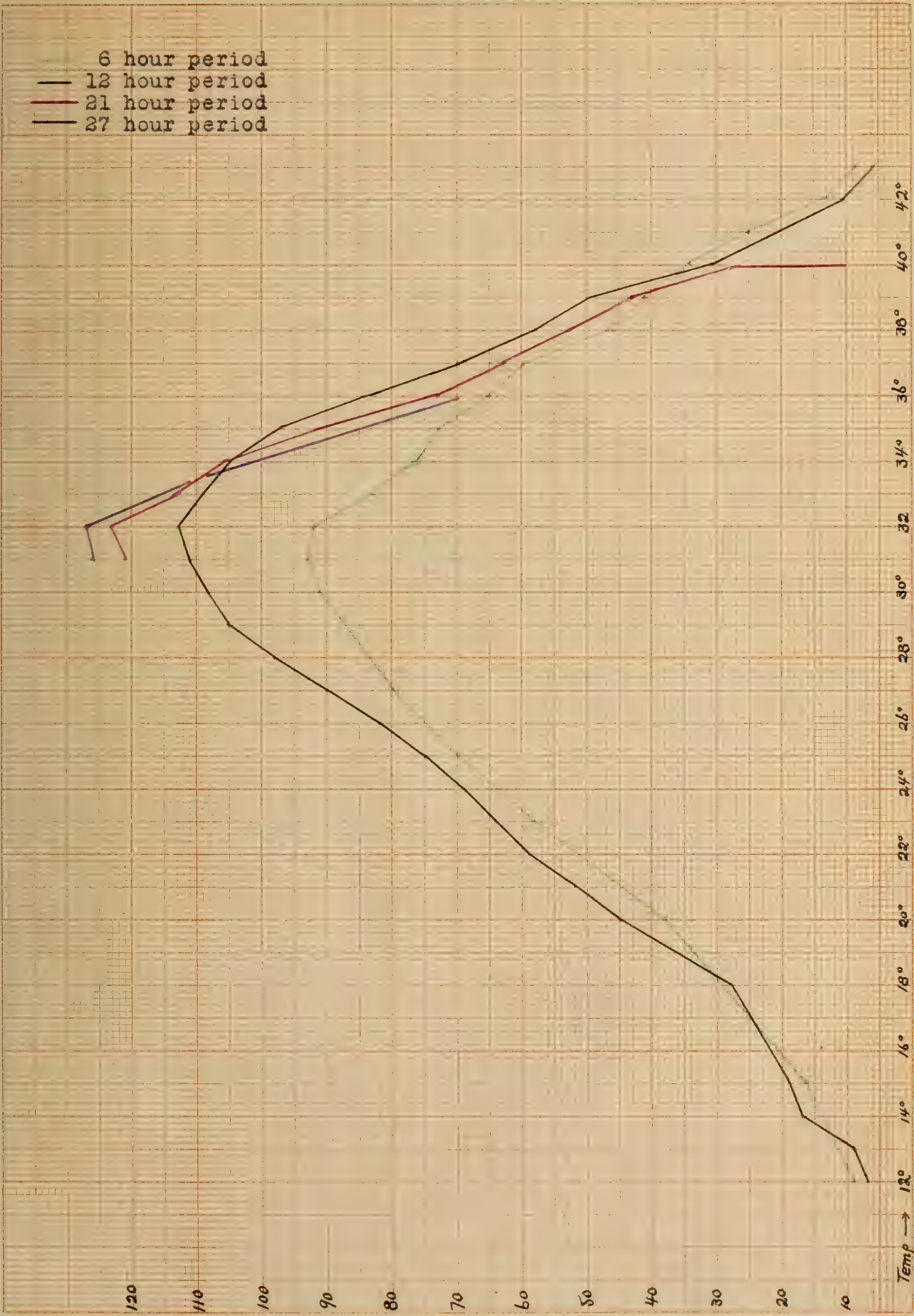
45
41°
42°
37°
43°
Hrs → 3
6
9
12
15
18
21
24
27
30
U. OF I. S. S. FORM 3


6 hour period
12 hour period
21 hour period
27 hour period
120
110
100
90
80
70
60
50
40
30
20
10
Temp →
12°
14°
16°
18°
20°
22°
24°
26°
28°
30°
32
34°
36°
38°
40°
42°

Phillip August Lehenbauer

Vita

1883, Nov. 1st.	Born in Marion County, Missouri.
1890-1897	Attended German Lutheran Parochial School, West Ely, Missouri.
1897-1899	Attended Public School, West Ely, Missouri.
1899-1901	Attended Van Rensselaer Academy, Rensselaer, Missouri
1901-1902	Attended Westminster Academy, Fulton, Missouri.
1902-1903	Taught in Public Schools, West Ely, Missouri.
1903-1907	Attended Westminster College, Fulton, Missouri. Student Assistant in Chemistry, 1906-1907.
1907-1909	Student and Assistant in Biology in James Millikin University, Decatur, Illinois.
1909-1912	Assistant in Botany, University of Illinois, Urbana.
1912-1914	Fellow in Botany, University of Illinois, Urbana.

1907 - A.B. Degree, Westminster College.

1909 - A.M. Degree, James Millikin University.